APPENDIX A
PRIORITIZATION OF URANIUM FLOWS

INTRODUCTION

On August 8, 1999, in response to a number of health effects allegations and concerns, the Secretary of Energy initiated an investigation of the radiological risks and control programs at the Paducah Gaseous Diffusion Plant. In pursuing that initiative, Deputy Secretary T. J. Glauthier, on September 15, 1999, issued a memorandum that, in part, directed the Department of Energy (DOE) to examine all constituents of the major streams of uranium that passed within and between DOE sites since the early days of operations. Included in this examination is the task of identifying the characteristics of those isotopic constituents that would be of concern to worker or public health and safety or the environment. Technetium, neptunium, and plutonium isotopes were specifically listed as potential concerns to be considered because trace amounts were known to be present in the uranium that had been recycled from reactor programs.

As a part of this effort, a team of DOE and DOE contractor employees was assembled[1] to characterize the relative hazards of uranium process streams. This team collectively possesses diverse experience in the processing, chemistry, and health consequences of the various forms of uranium used by DOE and its predecessor agencies. This document was produced by that team, and is to be used in preparing for further study of the historical flows of uranium within and between past and present DOE facilities.

This document discusses the general flows of uranium that have occurred throughout the history of DOE and its predecessor agencies, and introduces terms necessary to describe the types of uranium involved in those flows. The relative human radiological health hazards of uranium stream constituents are then described, along with the regulatory and scientific factors used in estimating those hazards, and the uncertainties of those estimations. Next, the available data concerning the uranium streams and the radiochemical analyses of their compositions are described, including the uncertainties in the analyses and other measurements. Finally, a means of categorizing the uranium flows and definitions of those categories is proposed.

SCOPE

This Appendix provides the technical basis for identifying the relative radiological health hazards of uranium stream constituents for the "Historical Generation and Flow of Recycled Uranium in the DOE Complex" (i.e., the mass balance project). The scope of the mass balance project and its report is the evaluation of all of the uranium process streams that used reactor-irradiated recycled uranium within the facilities of DOE and its predecessor agencies. The purpose is to track additional isotopic constituents in those streams resulting from recycled uranium; i.e., uranium that has been used in reactors and therefore contains transuranic isotopes, fission products, activation products, etc. The scope also includes an evaluation of the radiological impact of those additional radioisotopic components, which could in turn identify specific processes at specific facilities in which significant additional risks to workers resulted beyond those represented by the uranium.

[1] The members and affiliations of the team appear as Attachment G to this Appendix.

BACKGROUND ON DOE URANIUM PROCESSES

All uranium isotopes are radioactive. Consequently, the constituents of any given mass of uranium in any chemical form vary with time due to radioactive decay. The three major uranium isotopes found in uranium ores, namely ^{238}U, ^{235}U, and ^{234}U, all decay by alpha particle emission and, to a much lesser extent, by spontaneous fission. This introduces decay products such as thorium and radium isotopes as constituents. As a result of the presence of these constituents, uranium constitutes a radiological hazard not only from its own decay, but also from the radioactivity of its accumulated decay products. If uranium is chemically separated from its decay products, the resulting chemically pure uranium will slowly increase in radioactivity as further decay rebuilds the constituents that were removed. In particular, the first two decay products of ^{238}U, namely ^{234}Th and ^{234}Pa, will grow to be in equilibrium with the ^{238}U within about six months of the chemical separation. The further decay products of ^{234}Pa will grow very slowly, taking thousands of years to approach equilibrium.

Human uses of uranium can change its radioactivity in three significant ways: 1) by introducing fission and neutron-induced isotopes (isotopes generated by reactions caused by interactions with neutrons) through irradiation in a nuclear reactor; 2) by chemically removing decay, fission, and neutron-induced isotopes; and 3) by physically separating the uranium into isotopic fractions. This third process, as carried out by gaseous diffusion, produces two streams of uranium. One has a higher concentration of ^{235}U and ^{234}U and therefore has increased specific activity, and the other has a lower concentration of these isotopes and decreased specific activity.

From inception of the Manhattan Project to the present, DOE and its predecessor agencies have received several hundred thousand metric tons of uranium from foreign and domestic mining operations. Because of the value and scarcity of uranium, particularly in the early days of the Atomic Energy Commission, all scrap materials and waste streams that might contain recoverable quantities of uranium were returned to processing centers to be recycled. One source of uranium for recycling was spent fuel from government plutonium production reactors and domestic and foreign power and test reactors.

Irradiated uranium contains quantities of transuranic isotopes, including ^{237}Np and ^{239}Pu, fission product isotopes such as ^{137}Cs, ^{90}Sr, and ^{99}Tc, neutron activation isotopes such as ^{60}Co and ^{51}Cr, and man-made[2] uranium isotopes. Irradiated uranium was processed in the chemical separation plants to remove fission products, separate and recover the transuranic isotopes for other government applications, and recover the uranium remaining after irradiation and chemical processing for further use. Recovered uranium contained reactor-generated uranium isotopes and trace quantities of transuranic and fission product isotopes. These uranium isotopes were chemically identical to the natural uranium isotopes, and therefore could not be separated in the chemical separation process. The concentrations of the individual transuranic and fission isotopes remaining in the separated uranium depend upon the effectiveness of the chemical separation process for that specific element. Process specifications developed for the PUREX process found uranium product acceptable when ^{99}Tc did not exceed 10 parts per million (ppm),

[2]Man-made uranium isotopes are those created by irradiation. The most abundant man-made uranium isotope is ^{236}U from neutron capture by ^{235}U; ^{232}U is an eventual decay product of ^{236}U and ^{233}U has been made for nuclear fuel and weapons purpose from ^{232}Th irradiation.

^{237}Np did not exceed 50 parts per billion (ppb), and ^{239}Pu did not exceed 10 ppb. While the levels of these constituents in uranium recovered from PUREX are generally less than the process specification requirements and/or acceptance criteria, process upsets may have caused particular shipments to exceed specifications.

The specific activity of a radioactive material is the activity per unit mass of the material. Chemically purified natural uranium contains ^{238}U, small percentages of ^{235}U (approximately 0.7% by weight), and ^{234}U (approximately 0.05% by weight). It has a specific activity of 6.76×10^{-7} Curies per gram (Ci/g). This specific activity means that 1.5 metric tons of pure natural uranium has a total activity of one Curie[3]. When uranium is enriched by the gaseous diffusion process, the concentration of the lighter uranium isotopes, ^{235}U and ^{234}U, is increased relative to ^{238}U. Because the lighter uranium isotopes have higher specific activity (^{234}U at 6.2×10^{-3} Ci/g and ^{235}U at 2.2×10^{-6} Ci/g) than ^{238}U at 3.4×10^{-7} Ci/g, the enriched uranium has a higher total specific activity that is dependent on the level of enrichment. Depleted uranium has a lower specific activity.

Some of the additional constituents found in recycled irradiated uranium include ^{232}U, ^{233}U, ^{236}U, ^{237}Np (7.0×10^{-4} Ci/g), ^{239}Pu (6.2×10^{-2} Ci/g), and ^{99}Tc (1.7×10^{-2} Ci/g). These isotopes all exhibit higher specific activity than natural uranium. Of these constituents ^{236}U, ^{237}Np, and ^{239}Pu are alpha-emitting isotopes, while ^{99}Tc is a beta-emitting isotope (i.e., it decays by emitting electrons).

RADIATION SAFETY & HEALTH EFFECTS

Uranium is known to be both a radiological and a chemical (heavy metal kidney damage) hazard. As a consequence, health and safety programs for the handling of uranium and its compounds have been instituted to control exposures to workers, members of the public, and the environment. Though there are recognized external radiation levels associated with the handling of uranium parts and materials, the primary concern from a health and safety standpoint is restricting the intake of uranium materials into the body. Since the reactor-produced transuranic, fission, and activation products in recycled uranium streams are present in trace quantities only, the primary concern continues to be from potential internal doses[4]. The heavy metal chemical toxicity of low enriched uranium is always a potential hazard, but requires internal intake at or near the maximum permissible levels. The additional constituents do not contribute to the chemical toxicity, but even at relatively low levels, they can significantly contribute to the radiological dose from intake. The primary and most significant path of intake is through inhalation of suspended radioactive isotopes in the air.

To provide the guidance necessary to control occupational inhalation exposures to acceptable levels, national and international advisory organizations and regulatory agencies have established limits on the allowable concentrations of radioactive materials in air. These limits are termed Derived Air Concentration (DAC) values. The DAC values are based on Annual Limit on Intake (ALI), which is calculated to result in the maximum allowed committed radiological dose to a

[3] The Curie is the traditional unit of radioactive decay, being equal to the decay rate of one gram of radium, or 3.7×10^{10} disintegrations per second. The modern unit is the Becquerel, equal to one disintegration per second.

[4] "Dose" is used here and in all regulations and standards dealing with radiation effects to man the accumulated ionization delivered to a human being or a specific organ of a human being by ionizing radiation.

"standard man" from internal exposures. Materials with low DAC values pose a greater radiological risk than materials with higher DAC values. ALI and DAC values are established for individual radioisotopes of each element. Evaluation of the radiological impact of other constituents in uranium material can be effectively performed through comparison of each constituent's DAC value to that of natural uranium.

Applicable regulations containing DAC values include 10 CFR 20 (NRC) and 10 CFR 835 (DOE). A comparison of the regulations shows interagency differences in DAC values for the isotopes ^{239}Pu, ^{240}Pu, and ^{241}Am. This report will use DAC values set forth by DOE (i.e., 10 CFR 835) for dose evaluation purposes.

Because uranium is an inherently radioactive material, the presence of additional radioactivity because of the constituent component presents an incremental radiological burden. For this analysis and report, the incremental radiological burden is considered significant when the potential inhalation dose is increased by 10% or more by the summed contribution of all constituents. A 10% threshold is consistent with but more conservative than NRC guidance and control philosophy, such as that found in 10 CFR 20.1204(g)(2) and 1204(g)(3), which provide directions for determining effective DAC values and subsequent internal exposures, or 10 CFR 20.1502(b)(1), which gives directions to programs for requiring individual monitoring of internal occupational exposure.

The level of radiological significance is dependent both on the quantity of reactor-produced constituents present and on the lung retention class of the uranium material and the other constituents. The lung retention class differs among the various chemical compositions of uranium and the transuranic element plutonium. The lung retention classes used in current regulations are defined in ICRP Publication 30[5], which is the basis of the current governmental regulations. Table 1 lists lung retention classes of the most common uranium compounds, as provided in ICRP Publication 30.

Table 1. Lung Retention Classes

Class D	Class W
UF_6	UO_2, UO_3, U_3O_8
UO_2F_2	UF_4
$UO_2(NO_3)_2$	UCl_4

Because the DAC value of uranium varies with each lung retention class, radiological significance thresholds will be determined and applied independently for each separate lung classification.

The method used for calculating activity-based radiological significance threshold values is provided in the *Health Physics Manual of Good Practices for Uranium Facilities*[6], example 2 (page 2-23). The applicable equations can be combined and solved to give the following relationship: where f_{con} is the fractional constituent activity (relative to the uranium activity) and ΔH is the fraction of resultant inhalation dose attributable to the

Equation 1

$$f_{con} = \frac{(\Delta H)(DAC_{con})}{(1 - \Delta H)(DAC_U)}$$

[5]International Commission on Radiological Protection Publication 30, *Limits for Intakes of Radionuclides by Workers,* July 1978.

[6]*Health Physics Manual of Good Practices for Uranium Facilities,* EGG-2530, UC-41, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

constituent. Equation 1, for simplicity, considers only one constituent.

For application to the usual circumstance of more than one constituent, the values obtained must be prorated and summed. The constituent DAC (DAC_{con}) is the value given in 10 CFR 835 for each isotope and lung class. The uranium DAC (DAC_U) is essentially independent of enrichment (see Table 2).

Table 2. Derived Air Concentrations (DACs) Excerpted from 10 CFR 835, Appendix A (µCi/ml)

Isotope	D	W	Y
^{95}Zr	6×10^{-8}	2×10^{-7}	1×10^{-7}
^{95}Nb	—	5×10^{-7}	5×10^{-7}
^{99}Tc	2×10^{-6}	3×10^{-7}	—
^{103}Ru	7×10^{-7}	4×10^{-7}	3×10^{-7}
^{106}Ru	4×10^{-8}	2×10^{-8}	5×10^{-9}
^{125}Sb	1×10^{-6}	2×10^{-7}	—
^{137}Cs	7×10^{-8}	—	—
^{141}Ce	—	3×10^{-7}	2×10^{-7}
^{144}Ce	—	1×10^{-8}	6×10^{-9}
^{230}Th	—	3×10^{-12}	7×10^{-12}
^{232}U	9×10^{-11}	2×10^{-10}	3×10^{-12}
^{233}U	5×10^{-10}	3×10^{-10}	2×10^{-11}
^{234}U	5×10^{-10}	3×10^{-10}	2×10^{-11}
^{235}U	6×10^{-10}	3×10^{-10}	2×10^{-11}
^{236}U	6×10^{-10}	3×10^{-10}	2×10^{-11}
^{238}U	6×10^{-10}	3×10^{-10}	2×10^{-11}
^{237}Np	—	2×10^{-12}	—
^{238}Pu	—	3×10^{-12}	7×10^{-12}
^{239}Pu	—	2×10^{-12}	6×10^{-12}
^{240}Pu	—	2×10^{-12}	6×10^{-12}
^{241}Am	—	2×10^{-12}	—

Assuming the same lung retention classes and particle size distributions among the constituents and setting ΔH at 0.10 (10%), Table 3 provides the f_{con} values for significant constituents.

Each constituent, considered separately, in recycled irradiated uranium will not present an appreciable radiological dose hazard when present in fractional constituent activities less than Table 3 values. Solving Equation 1 for a 10% ($\Delta H = 0.1$) significance level reveals that isotopes with a DAC value greater than 9 times the uranium DAC value cannot provide a 10% dose contribution (i.e., f_{con} value exceeds unity). Therefore, ^{99}Tc, ^{234}Th, ^{234}Pa, and Class Y ^{241}Pu can never present an appreciable additional inhalation hazard when uranium is also present, since any combination of these radioisotopes cannot increase the potential inhalation dose consequences of an equivalent amount of uranium by more than 10%.

Applying these threshold values to the various uranium materials may require conversion to mass-based quantities, such as ppb of uranium. Such a conversion requires application of uranium and its other constituents' specific activities.

Because the specific activity of uranium increases with enrichment, mass-based threshold values will also increase with the level of enrichment. The specific activity of enriched or depleted uranium is determined using guidance provided in Appendix B of 10 CFR 20. For depleted uranium, the specific activity is equivalent to 3.6×10^{-7} Ci/g. For enrichments (E) greater than 0.7% ^{235}U (by weight), Equation 2 is used to calculate the specific activity.

Equation 2

$$\text{Specific Activity} = 0.4+0.38E+0.0034E^2 \times 10^{-6} \text{ Ci/g}$$

Table 3. f_{con} Values

Lung Class	^{236}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
D	1.1×10^{1}	3.7×10^{4}	5.6×10^{4}	3.7×10^{4}	3.7×10^{4}	1.9×10^{2}	3.7×10^{4}
W	1.1×10^{1}	7.4×10^{4}	1.1×10^{3}	7.4×10^{4}	7.4×10^{4}	3.7×10^{2}	7.4×10^{4}
Y	1.1×10^{1}	1.1×10^{2}	3.9×10^{2}	3.3×10^{2}	3.3×10^{2}	n/a	1.1×10^{2}

Equation 2 illustrates the effect of enrichment on the radioactivity of the uranium product. This effect is due to the increase in relative quantity of the ^{234}U isotope, which has a greater specific activity than either ^{235}U or ^{238}U, and secondarily due to the increase in the relative quantity of ^{235}U. Because each reactor-produced constituent isotope has a unique specific activity, mass-based "thresholds" (i.e., the concentration at which each uranium constituent contributes 10% of the potential inhalation dose) must be calculated separately for each constituent and the appropriate uranium enrichment level. These thresholds must be prorated among the constituents such that the overall threshold, which indicates a potentially significant exposure, is the summation of prorated thresholds of all the constituents. Although the isotopes ^{239}Pu and ^{240}Pu cannot be differentiated through conventional radioisotopic analysis methods, mass-based thresholds will be listed for both isotopes to allow comparison with historical data.

Attachments A, B, and C list constituent thresholds, in ppb, for various enrichments of Classes D, W, and Y uranium, respectively. Equation 3 was used to derive these mass-based uranium values $(f_{con})_i$ for each constituent, where SA_U is the specific activity of uranium in units of Becquerels per gram (Bq/g) and SA_i is the specific activity of constituent in units of Becquerels per nanogram (Bq/ng).

Equation 3

$$PPB_i = \frac{(f_{con})_i \, SA_U}{SA_i} \quad \text{parts-per-billion}$$

Attachments D, E, and F provide "semi-mass-based" thresholds in units of picoCuries (pCi) of constituent per gram of total uranium. Both the fractional constituent activity and mass ratios listed in the tables are isotope-specific. If several constituent isotopes are present, comparing the constituent isotopic data to the thresholds listed in the attachments will require application of the "sum-of-fractions" rule.

COMPARISON WITH CURRENT REGULATORY CRITERIA

Several regulatory criteria and technical standards for uranium isotopic purity are available. Comparison of these criteria to the values in the attachments confirms that the values in the attachments are consistent with accepted practice.

U.S. Department of Transportation

The definitions in 49 CFR 173 contain the statement "Unirradiated uranium means uranium containing not more than 10^{-6} grams of plutonium per gram of ^{235}U and a fission product activity of not more than 9 MBq (0.24 milliCuries) of fission products per gram of ^{235}U." For the lowest enrichment of uranium considered in the Appendices (0.2% recycled from the total uranium), these values correspond to 2 ppb of plutonium per total uranium, and 28,000 ppb (i.e., 28 parts per million) ^{99}Tc per total uranium.

International Atomic Energy Agency

IAEA Safety Standards Series, No. ST-1, "Regulations for the Safety Transport of Radioactive Material," 1996 Edition, defines unirradiated uranium as "Unirradiated uranium shall mean uranium containing not more than 2×10^3 Bq of plutonium per gram of ^{235}U, not more than 9×10^6 Bq of fission products per gram of ^{235}U, and not more than 5×10^{-3} g of ^{236}U per gram of ^{235}U." For depleted uranium, 0.2% ^{235}U, this would be the same fission product limit as in 49 CFR 173 on a total uranium basis, 10 parts per million ^{236}U per total uranium, and a million

Becquerels or 27 mCi of plutonium per gram of total uranium.

U. S. Nuclear Regulatory Commission

10 CFR 20.1204, *Determination of Internal Exposure*, states, in part, "(g) When a mixture of radionuclides in air exists, licensees may disregard certain radionuclides in the mixture if:

(1) The licensee uses the total activity of the mixture in demonstrating compliance with the dose limits in §20.1201 and in complying with the monitoring requirements in §20.1502(b);

(2) The concentration of any radionuclide disregarded is less than 10% of its DAC; and

(3) The sum of these percentages for all of the radionuclides disregarded in the mixture does not exceed 30%."

Under this regulation, the additional internal exposures of workers to small radionuclide air concentrations may be disregarded.

10 CFR 20.1502 states, in part,

"(b) Each licensee shall monitor (see §20.1204) the occupational intake of radioactive material by and assess the committed effective dose equivalent to:

(1) Adults likely to receive, in 1 year, an intake in excess of 10 percent of the applicable ALI(s) in Table 1, Columns 1 and 2, of appendix B to §20.1001-20.2402;"

In the Appendices to 10 CFR 20, tables of ALIs and DACs are given, with the information that these are algebraically related - the ALI divided by 2.4 x 10^9 yields the DAC. This regulation is consistent with 10 CFR 20.1204, quoted above, in that 10% of an estimated exposure within regulatory limits is not considered to be significant.

10 CFR 40.13 defines "unimportant quantities of source material." Paragraph (c)(5) exempts from this part "uranium contained in counterweights installed in aircraft, rockets, projectiles, missiles, or stored or handled in connection with installation or removal of such counterweights…," provided that these are labeled as "depleted uranium" and were manufactured under specific license issued by the NRC or the AEC.

Depleted uranium armor for the M1 Series Main Battle Tank is supplied by DOE for installation by Army contractors. The NRC licenses for the Army, its vendors, and contractors did not contain provisions for trace constituents. These licenses have been amended to include the following paragraph:

"Transuranics and technetium-99 contaminants in uranium depleted in uranium-235 will not exceed a total of 100 picoCuries/gram of each transuranic and not to exceed 500 picoCuries/gram total for all transuranics. Not to exceed 500 picoCuries/gram of technetium-99."

American Society for Testing and Materials (ASTM)

"Standard Specification for Uranium Hexafluoride for Enrichment," ASTM Designation C 787-96, defines "commercial natural uranium" as being distinct from "virgin natural uranium." Commercial natural uranium, by this industry standard, should contain less than 20,000 ppb ^{236}U and less than 1 ppb ^{99}Tc. The standard states that the ^{236}U limit is a threshold for more detailed isotopic analysis; it does not suggest that the limit is for worker radiological protection. Virgin natural uranium does not contain detectable amounts of ^{236}U. This standard also sets limits of 0.84% for the maximum ^{236}U content, and 500 ppb for the maximum ^{99}Tc content of reprocessed uranium.

DESCRIPTION OF URANIUM PROCESSES

The facilities of DOE and its predecessor agencies received approximately one million

tons of uranium from ore. This uranium was sequentially converted to UO_3, then UF_4, and then UF_6. This last, uranium hexafluoride, is the gas fed into the cascades of the gaseous diffusion plants.

The product from the gaseous diffusion plants was converted into either uranium oxide or uranium metal.

Product from the gaseous diffusion plants was used for a variety of purposes, but the purpose of primary importance to the mass balance project was the production of fuel and targets for nuclear weapons production reactors. This uranium, after irradiation, was chemically separated from all but small amounts of other elements and reused.

Of the processes through which recycled uranium passed, only two affected its constituent concentrations greatly. First, the conversion of UF_4 to UF_6 selectively volatilized uranium, while leaving transuranic elements largely behind as ash combined with unreacted uranium. This ash contained only a small fraction of the uranium processed, while retaining most of the transuranics. The further processing of this ash to recover the remaining unreacted uranium is the most important source of potential radiological doses in the processing of uranium.

Second, the gaseous diffusion cascade itself concentrated the constituents. Transuranic element fluorides entering the cascade were concentrated in the early stages of the cascade due to their lesser stability and volatility in comparison to UF_6. Hence, the transuranic elements were greatly concentrated in decontamination streams generated during the maintenance and replacement of cascade equipment and barrier material. Meanwhile, technetium, being very much lighter in mass than uranium, concentrated with the light-mass cascade product (i.e., with the ^{235}U fraction). In addition, during some periods of operation, magnesium fluoride "traps" were employed within the cascade to adsorb the technetium, concentrating it in a waste stream.

HISTORICAL AND CURRENT PROCESSES WITH POTENTIAL FOR EXPOSURE

The potential for exposure to workers through past and present processes arises from both normal operations and possible accidents. The potential for exposures is much less now than it was in the past because no uranium has been recycled for many years, practices have been improved, and more stringent health and safety procedures reduce the accident potential.

Opportunities for exposure to workers in the past were primarily at the point of transfer of compounds or solutions in or out of containers, machining of metals containing transuranics, or converting uranium metals back to an oxide. Small amounts of dust would be generated when handling oxide, or, in the case of liquids, an occasional spill or simply breathing vapors could expose workers. The machining of metals would also result in a fine dust which could be taken into the lungs. Inhalation was also possible from the combustion of metal shavings or scrap from machining operations. Because of the potential problems, these operations are normally conducted in gloveboxes or other enclosures. Even in the event that some of these operations may have been conducted in the open, no significant uptake of transuranics would have been likely in these processes unless the operations involved a transformation of the material that resulted from accumulation of one or more of the constituents. Exposures would have been possible in emptying the feed production ash canisters or possibly feeding UF_4 into hoppers at the GDPs, for example. Other exposure potentials occur in the processing of

waste streams at any of the sites where transuranics have accumulated.

In present-day operations, accidental releases could occur at only a few sites that are still handling material containing transuranics. The most likely exposure scenario is a spill containing transuranic waste. This is possible at some sites. Manufacturing using material containing transuranics may still occur at some sites; however, the residual quantities of transuranics are very small in such material. Accidental breathing of dust from machining operations due to filter breakthrough is perhaps the most likely means to receive an uptake of material containing transuranics. Exposure to an oxidation event such as a uranium chip fire is possible; however, uranium in this form burns slowly, and the event would normally occur during an operation in a glovebox. Either the worker would be protected from exposure by the glovebox, or he would be pre-instructed to take the "see and flee" evasive action.

Other exposures may occur in processing uranium for recovery or in precipitating fission products, metals, and other constituents from the waste effluent.

RELATIONSHIPS AMONG RADIATION SAFETY, CHEMICAL PROCESSES, AND DATA ANALYSIS

The chemical processes used throughout the complex may either concentrate trace constituents from the uranium into a waste stream, thereby purifying the product uranium, or may carry the constituents along with the uranium in virtually unchanged concentration. In addition, the sampling and radiochemical analyses performed on uranium streams may or may not vary markedly with time or other unknown process variables, and may be sufficiently close to the detectable limits for the trace constituents to be subject to great uncertainty.

The objectives of the weapons program included producing as much plutonium as possible from the limited supply of uranium by reactor irradiation. This led to development of progressively more effective separations of plutonium from uranium. The need for neptunium in the space program, where it is used to produce the ^{238}Pu heat source for thermoelectric generators, also led to its deliberate recovery from uranium process streams.

In addition to intended separations, the differing chemical properties of uranium, neptunium, and plutonium caused further purification of uranium wherever the process stream involved its conversion into UF_6 gas, since neptunium and plutonium fluoride are both less volatile and less stable than UF_6.

The potential radiological doses posed by the constituents in uranium generally become appreciable relative to uranium itself only in the waste streams generated by the intentional and unintentional elemental separations. Of particular note is the ash created by the conversion of UF_4 to UF_6 and the decontamination wastes of cascade equipment and UF_6 storage and transport cylinders. In these and similar materials, the ratio of transuranics to uranium can be greatly increased such that the radiological hazard of the material becomes an appreciable fraction of that of the uranium itself.

PROCEDURE FOR EXCLUSION OF RECYCLED URANIUM FLOWS

As discussed earlier, the inherent radiological risk from the naturally occurring uranium isotopes has led to requirements for programs to limit worker exposures to acceptable levels. Such programs must address the constituents in irradiated uranium if they are capable of any appreciable additional dose over that of the uranium itself. The generally accepted level of additional dose is 10%

of that of the uranium, which is very much smaller than the uncertainties in the assumptions involved in estimating doses.

While the major uranium process streams are relatively free of transuranic and fission product isotopes, further processing or reactions with container materials during transportation are capable of concentrating those constituents in unwanted by-product or in waste materials from decontamination efforts. To ensure that all uranium streams that are capable of causing appreciable transuranic doses are tracked, it is necessary to consider uranium forms containing very small concentrations of other constituents if there is a likelihood of further processing that would result in a byproduct or waste stream that concentrated those constituents. Indeed, the tracking of these concentrated process streams is of much greater importance in the recreation of potential worker exposures to those constituents than the tracking of the uranium itself.

Uranium streams which are substantially below the level of 10% of potential radiological dose from other constituents and which are also expected to be the final product or waste, with no further processing, are incapable of causing appreciably greater doses than that caused by the uranium content itself. Such end-products are beyond the scope of the goal of the uranium mass balance project.

To determine the fraction of the potential inhalation doses of the constituents in a sample of uranium or its compounds, it is first necessary to establish the lung retention classification of that sample. These are given in Table 1. It is to be assumed that the lung retention classification of the constituents is the same as that of the uranium itself. The most restrictive class is D, although this is associated with those chemical forms of uranium least likely to cause a radiological risk by inhalation. If the lung retention class cannot be established, it is conservative to assume class D.

LUNG RETENTION CLASS		
Class D	**Class W**	**Class Y**
UF_6, UO_2F_2, UNH, $UO_2(NO_3)_2$	UO_3, UF_4, UCl_4, UO_2, U_3O_8	Uranium Carbide, Alloys, and Ceramics

Table 2 contains the threshold fractional constituent levels, relative to uranium, of each transuranic constituent in each lung retention class corresponding to 10% of the uranium inhalation dose. These entries can be prorated to the particular concentrations of isotopes in any uranium sample.

There are six attachments to this report, in which the ppb and pCi per gram of constituents corresponding to 10% potential inhalation dose relative to uranium are given for each lung retention class and selected uranium enrichments. It should be noted that the ppb and grams referred to in these attachments must be interpreted as relative to the uranium content of the sample; i.e., if only 50% by weight of the sample is uranium, then an analysis given in pCi per gram of sample must be doubled to be expressed as pCi per gram of uranium.

As a generally applicable method of calculation, the information in Appendix A to 10 CFR 835 can be used as follows:

Conversions

1 microCurie
= 37,000 Becquerels
= 2.2 x 10^6 dpm (disintegrations/minute)
= 1 x 10^6 picoCuries

1) Establish lung retention class of the uranium: D (day), W (week), or Y (year).

The assumption is to be made that the constituents are in the same lung class as the uranium matrix which contains them. If in doubt, it is conservative to choose the class having the *highest* DAC for the uranium summation, and the *lowest* DAC for the constituents.

2) Create two worksheets. On one, list the uranium isotopes ^{234}U, ^{235}U, and ^{238}U in the first column. These isotopes are those present in naturally occurring uranium ores. On the second worksheet, list all other radioisotopes, or the constituents. If no analytical data on all likely constituents exist, and analyses of similar streams and process knowledge cannot be used to reliably estimate their concentration, then discontinue this procedure and track the stream as part of the mass balance project.

In the second column of each worksheet, enter the concentration of that radioisotope and the units in which that concentration is measured. If any constituent is believed to be present but has not been analyzed, insert a footnote stating the basis for estimating its concentration.

In the third column of each worksheet, enter the concentration in the second column, converted into microCuries per gram of uranium. Note that the comparison to be made is between the summed potential doses from the constituents and that of the uranium. Except for pure metallic uranium, the uranium will be less than 100% of the sample, and concentrations available in terms of per gram of sample will have to be increased.

The most common unit for radioassays is pCi. Often, ^{239}Pu and ^{240}Pu will be reported as the sum of the activities of both, since it is experimentally difficult to resolve these two isotopes. Where this is the case, simply enter one row in the worksheet for the sum.

The dominant uranium isotopes are often reported as weight-percent of uranium (100 times the grams of isotope per gram of uranium). These can be easily converted to microCuries per gram by using specific activities (such as in Table 1 of the main body of this project plan) and multiplying each by the grams of isotope per gram of uranium.

3) From Appendix A of 10 CFR 835 (excerpted in Table 3), select the appropriate DAC values for each isotope present. Some elements will not have entries for all lung retention classes. Neptunium, for example, is given only for Class W, and elements insoluble in neutral solution will generally not have Class D entries. If a needed entry is blank, select the nearest DAC for that isotope. Note that all DACs in the attached table are in microCuries per milliliter. 10 CFR 835, Appendix A also has tables in terms of Becquerels per milliliter. Enter these DAC values into the fourth column of each worksheet.

4) In the fifth column, enter the radioisotopic concentration relative to uranium divided by the DAC values for each radioisotope. Sum the entries in column five separately for each of the two worksheets. The results will be in units of specific volume, milliliters per gram, at which the worksheet's radioisotopes equal the DAC.

5) Divide the constituent summation by the uranium summation. If the dimensionless result of this division is significantly less than 0.1 (10%) and there is process knowledge that no further chemical operations occurred on this stream, the stream may be excluded from further tracking. If there is reason to suppose that further chemical operations will concentrate the constituents; for example, the stream is UO_3 or UF_4, then the ratio must be less than 0.001 (0.1%) in order to be excluded.

If the uranium sample in question is a final product or a waste to be eventually disposed, then it is out of the scope of this initiative if the constituents comprise less than 10% of the potential inhalation dose.

If, however, the uranium is reasonably expected to undergo further processing, or to be transported to another site for potential processing, then the possibility of the creation of a more concentrated byproduct or waste stream must be considered. Instances are known to exist of UF_4 residues from fluoridation that had concen-

trations of plutonium and neptunium hundreds of times greater than the original material. In these cases, the uranium was selectively volatilized as UF_6 gas, while the other elements present remained in the solid phase. Whenever such concentration processes are possible, the uranium and its constituents should be tracked if the constituents comprise over 10% of the potential inhalation dose as calculated above. Where there is doubt or where constituent concentrations are marginal or unknown, the uranium should be conservatively kept within scope.

SAMPLE CALCULATIONS

Case in which inclusion can be demonstrated by considering a single constituent by comparison to the Attachments.

In 1966, NLO, Inc. received shipments of uranyl nitrate totaling 103,469 kg of uranium content, having an average concentration of 6.7 ppb plutonium, and enrichment of approximately 1%. No other analytical results of these shipments are available. From Table 1, uranyl nitrate is in lung retention class D. From Attachment A, 1% enriched uranium containing over 4.72 ppb ^{239}Pu has over 10% of its potential inhalation dose due to plutonium. This uranium must, therefore, be in the scope of the initiative, even without considering the likely presence of other constituents for which no analyses are available. In this case, the plutonium concentration alone was sufficient to demonstrate the need to track the material, and it was unnecessary to prorate the neptunium and plutonium contributions to the total potential transuranium inhalation dose.

Case in which process knowledge permits the decision to include a uranium stream, virtually regardless of constituent concentration.

Feed materials to the gaseous diffusion process generally consist of UO_3 or UF_4. The first of these is usually converted into the second, and the UF_4 further oxidized to the volatile UF_6. As discussed earlier, this later process volatilizes much purer uranium, while leaving behind a solid residue in which less volatile constituents, including Pu and Np, are greatly concentrated. From Table 1, these feed materials are both in lung retention class W. While the enrichment of this material is variable, it is typically approximated at 1%. From Attachment E, 10% of 1% enriched uranium potential inhalation dose can be obtained from either 579 pCi/gram of $^{239}Pu/^{240}Pu$, or ^{237}Np, or any combination of those two concentrations, summing to 579 pCi/gram.

Because these feed materials when fluorinated are expected to produce a byproduct stream with neptunium and plutonium concentrations about two orders of magnitude greater than that of the original material, it is prudent to track this material if its $^{239}Pu/^{240}Pu$ and ^{237}Np concentrations sum to 5.79 pCi/gram or more (from Attachment B, these concentrations are equivalent to about 0.1 ppb ^{239}Pu and 8 ppb ^{237}Np, or any linear combination of these concentrations). If other constituents must be considered, linear combinations from Attachment E must also be summed.

If the constituents that must be considered include more than those contained in Table 2 or the attachments, then the five-step calculation and the information in the appendix to 10 CFR 835, outlined earlier, must be used.

ATTACHMENT A

CLASS D CONSTITUENT MATERIALS - PPB VALUES

Enrichment (% U-235 by Weight)	U-236 ppb	Np-237 ppb	Pu-238 ppb	Pu-239 ppb	Pu-240 ppb	Pu-241 ppb	Am-241 ppb	Specific Activity of Uranium (Bq/g)
0.2	6.10E+05	1.89E+02	1.15E-02	2.17E+00	5.85E-01	6.62E-02	3.87E-02	1.33E+04
0.72	1.15E+06	3.56E+02	2.17E-02	4.07E+00	1.10E+00	1.24E-01	7.28E-02	2.50E+04
1	1.33E+06	4.12E+02	2.52E-02	4.72E+00	1.28E+00	1.44E-01	8.44E-02	2.90E+04
2	1.99E+06	6.18E+02	3.77E-02	7.08E+00	1.91E+00	2.16E-01	1.27E-01	4.34E+04
3	2.66E+06	8.27E+02	5.05E-02	9.47E+00	2.56E+00	2.89E-01	1.69E-01	5.81E+04
4	3.35E+06	1.04E+03	6.34E-02	1.19E+01	3.21E+00	3.63E-01	2.13E-01	7.31E+04
5	4.04E+06	1.26E+03	7.66E-02	1.44E+01	3.88E+00	4.39E-01	2.57E-01	8.82E+04
6	4.75E+06	1.48E+03	9.00E-02	1.69E+01	4.56E+00	5.16E-01	3.02E-01	1.04E+05
7	5.47E+06	1.70E+03	1.04E-01	1.95E+01	5.25E+00	5.94E-01	3.48E-01	1.19E+05
8	6.20E+06	1.93E+03	1.17E-01	2.21E+01	5.95E+00	6.73E-01	3.94E-01	1.35E+05
9	6.95E+06	2.16E+03	1.32E-01	2.47E+01	6.67E+00	7.54E-01	4.41E-01	1.52E+05
10	7.70E+06	2.39E+03	1.46E-01	2.74E+01	7.39E+00	8.36E-01	4.89E-01	1.68E+05
15	1.16E+07	3.61E+03	2.21E-01	4.14E+01	1.12E+01	1.26E+00	7.40E-01	2.54E+05
20	1.59E+07	4.93E+03	3.01E-01	5.64E+01	1.52E+01	1.72E+00	1.01E+00	3.46E+05
25	2.04E+07	6.33E+03	3.86E-01	7.25E+01	1.96E+01	2.21E+00	1.30E+00	4.45E+05
30	2.52E+07	7.82E+03	4.77E-01	8.96E+01	2.42E+01	2.73E+00	1.60E+00	5.50E+05
35	3.03E+07	9.41E+03	5.74E-01	1.08E+02	2.91E+01	3.29E+00	1.93E+00	6.61E+05
40	3.57E+07	1.11E+04	6.76E-01	1.27E+02	3.42E+01	3.87E+00	2.27E+00	7.78E+05
45	4.14E+07	1.28E+04	7.83E-01	1.47E+02	3.97E+01	4.49E+00	2.63E+00	9.02E+05
50	4.73E+07	1.47E+04	8.96E-01	1.68E+02	4.54E+01	5.13E+00	3.01E+00	1.03E+06
55	5.36E+07	1.66E+04	1.01E+00	1.90E+02	5.14E+01	5.81E+00	3.40E+00	1.17E+06
60	6.01E+07	1.87E+04	1.14E+00	2.14E+02	5.77E+01	6.52E+00	3.82E+00	1.31E+06
65	6.69E+07	2.08E+04	1.27E+00	2.38E+02	6.42E+01	7.26E+00	4.25E+00	1.46E+06
70	7.40E+07	2.30E+04	1.40E+00	2.63E+02	7.11E+01	8.03E+00	4.71E+00	1.62E+06
75	8.14E+07	2.53E+04	1.54E+00	2.90E+02	7.82E+01	8.84E+00	5.18E+00	1.78E+06
80	8.91E+07	2.77E+04	1.69E+00	3.17E+02	8.56E+01	9.67E+00	5.67E+00	1.94E+06
85	9.71E+07	3.02E+04	1.84E+00	3.45E+02	9.32E+01	1.05E+01	6.17E+00	2.12E+06
90	1.05E+08	3.27E+04	2.00E+00	3.75E+02	1.01E+02	1.14E+01	6.70E+00	2.30E+06
95	1.14E+08	3.54E+04	2.16E+00	4.05E+02	1.09E+02	1.24E+01	7.24E+00	2.49E+06

ppb = parts per billion mass of uranium

ATTACHMENT B

CLASS W CONSTITUENT MATERIALS - PPB VALUES

Enrichment (% U-235 by Weight)	U-236 ppb	Np-237 ppb	Pu-238 ppb	Pu-239 ppb	Pu-240 ppb	Pu-241 ppb	Am-241 ppb	Specific Activity of Uranium (Bq/g)
0.2	6.10E+05	3.79E+02	2.27E-02	4.34E+00	1.17E+00	1.29E-01	7.75E-02	1.33E+04
0.72	1.15E+06	7.11E+02	4.26E-02	8.15E+00	2.20E+00	2.42E-01	1.46E-01	2.50E+04
1	1.33E+06	8.25E+02	4.94E-02	9.45E+00	2.55E+00	2.81E-01	1.69E-01	2.90E+04
2	1.99E+06	1.24E+03	7.41E-02	1.42E+01	3.82E+00	4.21E-01	2.53E-01	4.34E+04
3	2.66E+06	1.65E+03	9.91E-02	1.89E+01	5.11E+00	5.63E-01	3.39E-01	5.81E+04
4	3.35E+06	2.08E+03	1.25E-01	2.38E+01	6.43E+00	7.08E-01	4.26E-01	7.31E+04
5	4.04E+06	2.51E+03	1.50E-01	2.88E+01	7.76E+00	8.55E-01	5.14E-01	8.82E+04
6	4.75E+06	2.95E+03	1.77E-01	3.38E+01	9.12E+00	1.00E+00	6.04E-01	1.04E+05
7	5.47E+06	3.40E+03	2.04E-01	3.89E+01	1.05E+01	1.16E+00	6.96E-01	1.19E+05
8	6.20E+06	3.85E+03	2.31E-01	4.41E+01	1.19E+01	1.31E+00	7.89E-01	1.35E+05
9	6.95E+06	4.31E+03	2.58E-01	4.94E+01	1.33E+01	1.47E+00	8.83E-01	1.52E+05
10	7.70E+06	4.78E+03	2.86E-01	5.48E+01	1.48E+01	1.63E+00	9.79E-01	1.68E+05
15	1.16E+07	7.23E+03	4.33E-01	8.28E+01	2.24E+01	2.46E+00	1.48E+00	2.54E+05
20	1.59E+07	9.86E+03	5.91E-01	1.13E+02	3.05E+01	3.35E+00	2.02E+00	3.46E+05
25	2.04E+07	1.27E+04	7.59E-01	1.45E+02	3.91E+01	4.31E+00	2.59E+00	4.45E+05
30	2.52E+07	1.56E+04	9.38E-01	1.79E+02	4.84E+01	5.33E+00	3.20E+00	5.50E+05
35	3.03E+07	1.88E+04	1.13E+00	2.15E+02	5.82E+01	6.40E+00	3.85E+00	6.61E+05
40	3.57E+07	2.22E+04	1.33E+00	2.54E+02	6.85E+01	7.54E+00	4.54E+00	7.78E+05
45	4.14E+07	2.57E+04	1.54E+00	2.94E+02	7.94E+01	8.74E+00	5.26E+00	9.02E+05
50	4.73E+07	2.94E+04	1.76E+00	3.37E+02	9.08E+01	1.00E+01	6.01E+00	1.03E+06
55	5.36E+07	3.33E+04	1.99E+00	3.81E+02	1.03E+02	1.13E+01	6.81E+00	1.17E+06
60	6.01E+07	3.73E+04	2.24E+00	4.27E+02	1.15E+02	1.27E+01	7.64E+00	1.31E+06
65	6.69E+07	4.16E+04	2.49E+00	4.76E+02	1.28E+02	1.41E+01	8.51E+00	1.46E+06
70	7.40E+07	4.60E+04	2.75E+00	5.27E+02	1.42E+02	1.56E+01	9.41E+00	1.62E+06
75	8.14E+07	5.06E+04	3.03E+00	5.79E+02	1.56E+02	1.72E+01	1.04E+01	1.78E+06
80	8.91E+07	5.53E+04	3.32E+00	6.34E+02	1.71E+02	1.88E+01	1.13E+01	1.94E+06
85	9.71E+07	6.03E+04	3.61E+00	6.91E+02	1.86E+02	2.05E+01	1.23E+01	2.12E+06
90	1.05E+08	6.54E+04	3.92E+00	7.50E+02	2.02E+02	2.23E+01	1.34E+01	2.30E+06
95	1.14E+08	7.08E+04	4.24E+00	8.10E+02	2.19E+02	2.41E+01	1.45E+01	2.49E+06

ppb = parts per billion mass of uranium

ATTACHMENT C

CLASS Y CONSTITUENT MATERIALS - PPB VALUES

Enrichment (% U-235 by Weight)	U-236 ppb	Np-237 ppb	Pu-238 ppb	Pu-239 ppb	Pu-240 ppb	Am-241 ppb	Specific Activity of Uranium (Bq/g)
0.2	6.10E+05	5.63E+03	8.04E-01	1.93E+02	5.22E+01	1.15E+00	1.33E+04
0.72	1.15E+06	1.06E+04	1.51E+00	3.63E+02	9.81E+01	2.16E+00	2.50E+04
1	1.33E+06	1.23E+04	1.75E+00	4.21E+02	1.14E+02	2.51E+00	2.90E+04
2	1.99E+06	1.84E+04	2.63E+00	6.31E+02	1.70E+02	3.76E+00	4.34E+04
3	2.66E+06	2.46E+04	3.51E+00	8.45E+02	2.28E+02	5.03E+00	5.81E+04
4	3.35E+06	3.09E+04	4.42E+00	1.06E+03	2.87E+02	6.33E+00	7.31E+04
5	4.04E+06	3.73E+04	5.34E+00	1.28E+03	3.46E+02	7.64E+00	8.82E+04
6	4.75E+06	4.39E+04	6.27E+00	1.51E+03	4.07E+02	8.98E+00	1.04E+05
7	5.47E+06	5.05E+04	7.22E+00	1.74E+03	4.68E+02	1.03E+01	1.19E+05
8	6.20E+06	5.73E+04	8.18E+00	1.97E+03	5.31E+02	1.17E+01	1.35E+05
9	6.95E+06	6.41E+04	9.16E+00	2.20E+03	5.95E+02	1.31E+01	1.52E+05
10	7.70E+06	7.11E+04	1.02E+01	2.44E+03	6.59E+02	1.45E+01	1.68E+05
15	1.16E+07	1.07E+05	1.54E+01	3.69E+03	9.97E+02	2.20E+01	2.54E+05
20	1.59E+07	1.47E+05	2.09E+01	5.03E+03	1.36E+03	3.00E+01	3.46E+05
25	2.04E+07	1.88E+05	2.69E+01	6.47E+03	1.75E+03	3.85E+01	4.45E+05
30	2.52E+07	2.33E+05	3.32E+01	7.99E+03	2.16E+03	4.76E+01	5.50E+05
35	3.03E+07	2.80E+05	4.00E+01	9.61E+03	2.59E+03	5.73E+01	6.61E+05
40	3.57E+07	3.29E+05	4.71E+01	1.13E+04	3.05E+03	6.74E+01	7.78E+05
45	4.14E+07	3.82E+05	5.46E+01	1.31E+04	3.54E+03	7.81E+01	9.02E+05
50	4.73E+07	4.37E+05	6.24E+01	1.50E+04	4.05E+03	8.94E+01	1.03E+06
55	5.36E+07	4.94E+05	7.07E+01	1.70E+04	4.59E+03	1.01E+02	1.17E+06
60	6.01E+07	5.55E+05	7.93E+01	1.91E+04	5.15E+03	1.14E+02	1.31E+06
65	6.69E+07	6.18E+05	8.83E+01	2.12E+04	5.73E+03	1.26E+02	1.46E+06
70	7.40E+07	6.83E+05	9.77E+01	2.35E+04	6.34E+03	1.40E+02	1.62E+06
75	8.14E+07	7.52E+05	1.07E+02	2.58E+04	6.97E+03	1.54E+02	1.78E+06
80	8.91E+07	8.23E+05	1.18E+02	2.83E+04	7.63E+03	1.68E+02	1.94E+06
85	9.71E+07	8.96E+05	1.28E+02	3.08E+04	8.31E+03	1.84E+02	2.12E+06
90	1.05E+08	9.73E+05	1.39E+02	3.34E+04	9.02E+03	1.99E+02	2.30E+06
95	1.14E+08	1.05E+06	1.50E+02	3.61E+04	9.75E+03	2.15E+02	2.49E+06

ppb = parts per billion mass of uranium

ATTACHMENT D

CLASS D CONSTITUENT MATERIALS - pCi/g VALUES

Enrichment (% U-235 by Weight)	U-236 pCi/g	Np-237 pCi/g	Pu-238 pCi/g	Pu-239/240 pCi/g	Pu-241 pCi/g	Am-241 pCi/g	Specific Activity of Uranium (Bq/g)
0.2	3.95E+04	1.33E+02	2.01E+02	1.33E+02	6.82E+03	1.33E+02	1.33E+04
0.72	7.42E+04	2.50E+02	3.78E+02	2.50E+02	1.28E+04	2.50E+02	2.50E+04
1	8.61E+04	2.90E+02	4.38E+02	2.90E+02	1.49E+04	2.90E+02	2.90E+04
2	1.29E+05	4.34E+02	6.57E+02	4.34E+02	2.23E+04	4.34E+02	4.34E+04
3	1.73E+05	5.81E+02	8.79E+02	5.81E+02	2.98E+04	5.81E+02	5.81E+04
4	2.17E+05	7.30E+02	1.10E+03	7.30E+02	3.75E+04	7.30E+02	7.31E+04
5	2.62E+05	8.82E+02	1.33E+03	8.82E+02	4.53E+04	8.82E+02	8.82E+04
6	3.08E+05	1.04E+03	1.57E+03	1.04E+03	5.32E+04	1.04E+03	1.04E+05
7	3.55E+05	1.19E+03	1.81E+03	1.19E+03	6.12E+04	1.19E+03	1.19E+05
8	4.02E+05	1.35E+03	2.05E+03	1.35E+03	6.94E+04	1.35E+03	1.35E+05
9	4.50E+05	1.51E+03	2.29E+03	1.51E+03	7.77E+04	1.51E+03	1.52E+05
10	4.99E+05	1.68E+03	2.54E+03	1.68E+03	8.62E+04	1.68E+03	1.68E+05
15	7.54E+05	2.54E+03	3.84E+03	2.54E+03	1.30E+05	2.54E+03	2.54E+05
20	1.03E+06	3.46E+03	5.24E+03	3.46E+03	1.78E+05	3.46E+03	3.46E+05
25	1.32E+06	4.44E+03	6.73E+03	4.44E+03	2.28E+05	4.44E+03	4.45E+05
30	1.63E+06	5.49E+03	8.31E+03	5.49E+03	2.82E+05	5.49E+03	5.50E+05
35	1.96E+06	6.60E+03	9.99E+03	6.60E+03	3.39E+05	6.60E+03	6.61E+05
40	2.31E+06	7.78E+03	1.18E+04	7.78E+03	3.99E+05	7.78E+03	7.78E+05
45	2.68E+06	9.01E+03	1.36E+04	9.01E+03	4.63E+05	9.01E+03	9.02E+05
50	3.07E+06	1.03E+04	1.56E+04	1.03E+04	5.30E+05	1.03E+04	1.03E+06
55	3.47E+06	1.17E+04	1.77E+04	1.17E+04	6.00E+05	1.17E+04	1.17E+06
60	3.89E+06	1.31E+04	1.98E+04	1.31E+04	6.73E+05	1.31E+04	1.31E+06
65	4.34E+06	1.46E+04	2.21E+04	1.46E+04	7.49E+05	1.46E+04	1.46E+06
70	4.80E+06	1.61E+04	2.44E+04	1.61E+04	8.29E+05	1.61E+04	1.62E+06
75	5.28E+06	1.78E+04	2.69E+04	1.78E+04	9.12E+05	1.78E+04	1.78E+06
80	5.78E+06	1.94E+04	2.94E+04	1.94E+04	9.98E+05	1.94E+04	1.94E+06
85	6.29E+06	2.12E+04	3.20E+04	2.12E+04	1.09E+06	2.12E+04	2.12E+06
90	6.83E+06	2.30E+04	3.48E+04	2.30E+04	1.18E+06	2.30E+04	2.30E+06
95	7.38E+06	2.48E+04	3.76E+04	2.48E+04	1.28E+06	2.48E+04	2.49E+06

pCi/g = picoCuries of constituent per gram of total uranium

ATTACHMENT E

CLASS W CONSTITUENT MATERIALS - pCi/g VALUES

Enrichment (% U-235 by Weight)	U-236 pCi/g	Np-237 pCi/g	Pu-238 pCi/g	Pu-239/240 pCi/g	Pu-241 pCi/g	Am-241 pCi/g	Specific Activity of Uranium (Bq/g)
0.2	3.95E+04	2.66E+02	3.95E+02	2.66E+02	1.33E+04	2.66E+02	1.33E+04
0.72	7.42E+04	4.99E+02	7.42E+02	4.99E+02	2.50E+04	4.99E+02	2.50E+04
1	8.61E+04	5.79E+02	8.61E+02	5.79E+02	2.90E+04	5.79E+02	2.90E+04
2	1.29E+05	8.68E+02	1.29E+03	8.68E+02	4.34E+04	8.68E+02	4.34E+04
3	1.73E+05	1.16E+03	1.73E+03	1.16E+03	5.81E+04	1.16E+03	5.81E+04
4	2.17E+05	1.46E+03	2.17E+03	1.46E+03	7.30E+04	1.46E+03	7.31E+04
5	2.62E+05	1.76E+03	2.62E+03	1.76E+03	8.82E+04	1.76E+03	8.82E+04
6	3.08E+05	2.07E+03	3.08E+03	2.07E+03	1.04E+05	2.07E+03	1.04E+05
7	3.55E+05	2.39E+03	3.55E+03	2.39E+03	1.19E+05	2.39E+03	1.19E+05
8	4.02E+05	2.70E+03	4.02E+03	2.70E+03	1.35E+05	2.70E+03	1.35E+05
9	4.50E+05	3.03E+03	4.50E+03	3.03E+03	1.51E+05	3.03E+03	1.52E+05
10	4.99E+05	3.36E+03	4.99E+03	3.36E+03	1.68E+05	3.36E+03	1.68E+05
15	7.54E+05	5.08E+03	7.54E+03	5.08E+03	2.54E+05	5.08E+03	2.54E+05
20	1.03E+06	6.92E+03	1.03E+04	6.92E+03	3.46E+05	6.92E+03	3.46E+05
25	1.32E+06	8.89E+03	1.32E+04	8.89E+03	4.44E+05	8.89E+03	4.45E+05
30	1.63E+06	1.10E+04	1.63E+04	1.10E+04	5.49E+05	1.10E+04	5.50E+05
35	1.96E+06	1.32E+04	1.96E+04	1.32E+04	6.60E+05	1.32E+04	6.61E+05
40	2.31E+06	1.56E+04	2.31E+04	1.56E+04	7.78E+05	1.56E+04	7.78E+05
45	2.68E+06	1.80E+04	2.68E+04	1.80E+04	9.01E+05	1.80E+04	9.02E+05
50	3.07E+06	2.06E+04	3.07E+04	2.06E+04	1.03E+06	2.06E+04	1.03E+06
55	3.47E+06	2.33E+04	3.47E+04	2.33E+04	1.17E+06	2.33E+04	1.17E+06
60	3.89E+06	2.62E+04	3.89E+04	2.62E+04	1.31E+06	2.62E+04	1.31E+06
65	4.34E+06	2.92E+04	4.34E+04	2.92E+04	1.46E+06	2.92E+04	1.46E+06
70	4.80E+06	3.23E+04	4.80E+04	3.23E+04	1.61E+06	3.23E+04	1.62E+06
75	5.28E+06	3.55E+04	5.28E+04	3.55E+04	1.78E+06	3.55E+04	1.78E+06
80	5.78E+06	3.89E+04	5.78E+04	3.89E+04	1.94E+06	3.89E+04	1.94E+06
85	6.29E+06	4.23E+04	6.29E+04	4.23E+04	2.12E+06	4.23E+04	2.12E+06
90	6.83E+06	4.59E+04	6.83E+04	4.59E+04	2.30E+06	4.59E+04	2.30E+06
95	7.38E+06	4.97E+04	7.38E+04	4.97E+04	2.48E+06	4.97E+04	2.49E+06

pCi/g = picoCuries of constituent per gram of total uranium

ATTACHMENT F

CLASS Y CONSTITUENT MATERIALS - pCi/g VALUES

Enrichment (% U-235 by Weight)	U-236 pCi/g	Np-237 pCi/g	Pu-238 pCi/g	Pu-239/240 pCi/g	Am-241 pCi/g	Specific Activity of Uranium (Bq/g)
0.2	3.95E+04	3.95E+03	1.40E+04	1.19E+04	3.95E+03	1.33E+04
0.72	7.42E+04	7.42E+03	2.63E+04	2.23E+04	7.42E+03	2.50E+04
1	8.61E+04	8.61E+03	3.05E+04	2.58E+04	8.61E+03	2.90E+04
2	1.29E+05	1.29E+04	4.57E+04	3.87E+04	1.29E+04	4.34E+04
3	1.73E+05	1.73E+04	6.12E+04	5.18E+04	1.73E+04	5.81E+04
4	2.17E+05	2.17E+04	7.69E+04	6.51E+04	2.17E+04	7.31E+04
5	2.62E+05	2.62E+04	9.29E+04	7.86E+04	2.62E+04	8.82E+04
6	3.08E+05	3.08E+04	1.09E+05	9.24E+04	3.08E+04	1.04E+05
7	3.55E+05	3.55E+04	1.26E+05	1.06E+05	3.55E+04	1.19E+05
8	4.02E+05	4.02E+04	1.43E+05	1.21E+05	4.02E+04	1.35E+05
9	4.50E+05	4.50E+04	1.60E+05	1.35E+05	4.50E+04	1.52E+05
10	4.99E+05	4.99E+04	1.77E+05	1.50E+05	4.99E+04	1.68E+05
15	7.54E+05	7.54E+04	2.67E+05	2.26E+05	7.54E+04	2.54E+05
20	1.03E+06	1.03E+05	3.65E+05	3.09E+05	1.03E+05	3.46E+05
25	1.32E+06	1.32E+05	4.69E+05	3.96E+05	1.32E+05	4.45E+05
30	1.63E+06	1.63E+05	5.79E+05	4.90E+05	1.63E+05	5.50E+05
35	1.96E+06	1.96E+05	6.96E+05	5.89E+05	1.96E+05	6.61E+05
40	2.31E+06	2.31E+05	8.20E+05	6.94E+05	2.31E+05	7.78E+05
45	2.68E+06	2.68E+05	9.50E+05	8.04E+05	2.68E+05	9.02E+05
50	3.07E+06	3.07E+05	1.09E+06	9.20E+05	3.07E+05	1.03E+06
55	3.47E+06	3.47E+05	1.23E+06	1.04E+06	3.47E+05	1.17E+06
60	3.89E+06	3.89E+05	1.38E+06	1.17E+06	3.89E+05	1.31E+06
65	4.34E+06	4.34E+05	1.54E+06	1.30E+06	4.34E+05	1.46E+06
70	4.80E+06	4.80E+05	1.70E+06	1.44E+06	4.80E+05	1.62E+06
75	5.28E+06	5.28E+05	1.87E+06	1.58E+06	5.28E+05	1.78E+06
80	5.78E+06	5.78E+05	2.05E+06	1.73E+06	5.78E+05	1.94E+06
85	6.29E+06	6.29E+05	2.23E+06	1.89E+06	6.29E+05	2.12E+06
90	6.83E+06	6.83E+05	2.42E+06	2.05E+06	6.83E+05	2.30E+06
95	7.38E+06	7.38E+05	2.62E+06	2.21E+06	7.38E+05	2.49E+06

pCi/g = picoCuries of constituent per gram of total uranium

ATTACHMENT G

MEMBERS OF THE SUB-TEAM WHICH PREPARED ATTACHMENT A

Don C. Barg: B.A. in Physics from the University of Utah. Over 37 years of experience in health physics and occupational health protection and safety.

Rodney Bauman: Senior Health Physicist in the Environmental Safety and Health Department at the Weldon Spring Site Remedial Action Project. B.S and M.S. in Health Physics from the Georgia Institute of Technology.

James C. Carter: President of J. C. Carter Associates. B.S. and M.S. in Nuclear Engineering from North Carolina State University. Over 30 years experience in nuclear safety.

Robert W. Garber, Senior Scientist and Project Manager for Parallax, Inc. More than 25 years experience in chemistry, radiochemistry and environmental science with a Ph.D. in Environmental Analytical Chemistry from University of Pittsburgh, M.S. in Radiochemistry from St. Joseph's College, Philadelphia, PA., B.S. in Chemistry from Philadelphia College of Pharmacy and Science (now named University of the Sciences in Philadelphia).

Ronald E. Gill: Facility Engineer at the Specific Manufacturing Capability Project at the Idaho National Engineering and Environmental Laboratory. B.S. in Chemical Engineering from the University of Maryland.

Norris Johnson: Westinghouse Savannah River Company. B.A. in Physics and Mathematics from Berry College, M.S. in Nuclear Physics from Vanderbilt University. Over 27 years of experience in nuclear fuel and reactor operations and health physics.

John M. McKenzie: DOE Office of Naval Reactors. B.S. in Nuclear Engineering from the Rensselaer Polytechnical Institute. Over 19 years in naval nuclear propulsion, including 7 years in environment, safety and health matters.

William Neyer: Project Assessment Team Leader, Office of Safety and Assessment, DOE-FEMP. B.S. in chemistry. Over 30 years of experience in quality assurance, engineering design and DOE operations.

Jacques B. J. Read: Physical Scientist in the DOE Office of Nuclear Safety Policy and Standards. A.B. in Physical Chemistry from Princeton University, M.S. and Ph.D. in Theoretical and Nuclear Chemistry, respectively, from Yale University. Over 40 years of experience in nuclear science and technology.

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